

Particle Production and Hyper - nuclei experiments



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HADRON PHYSICS

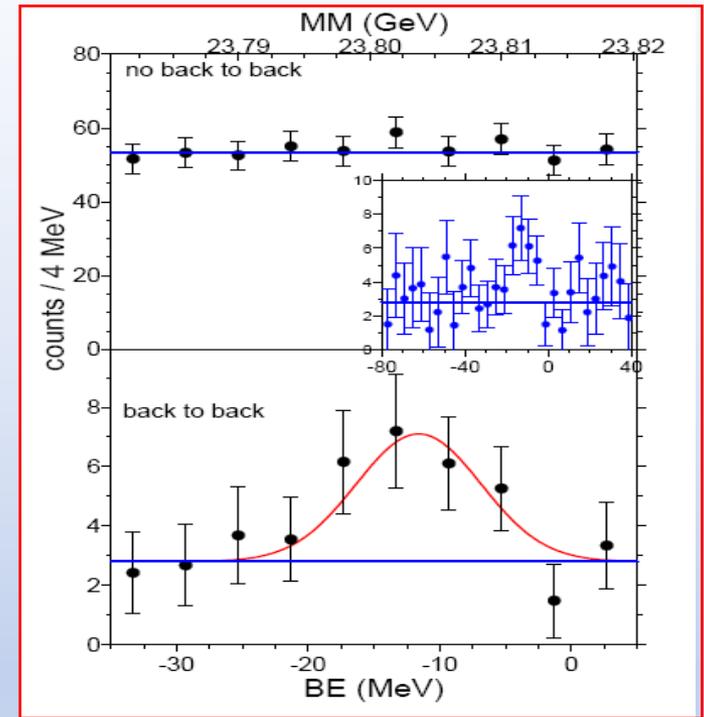
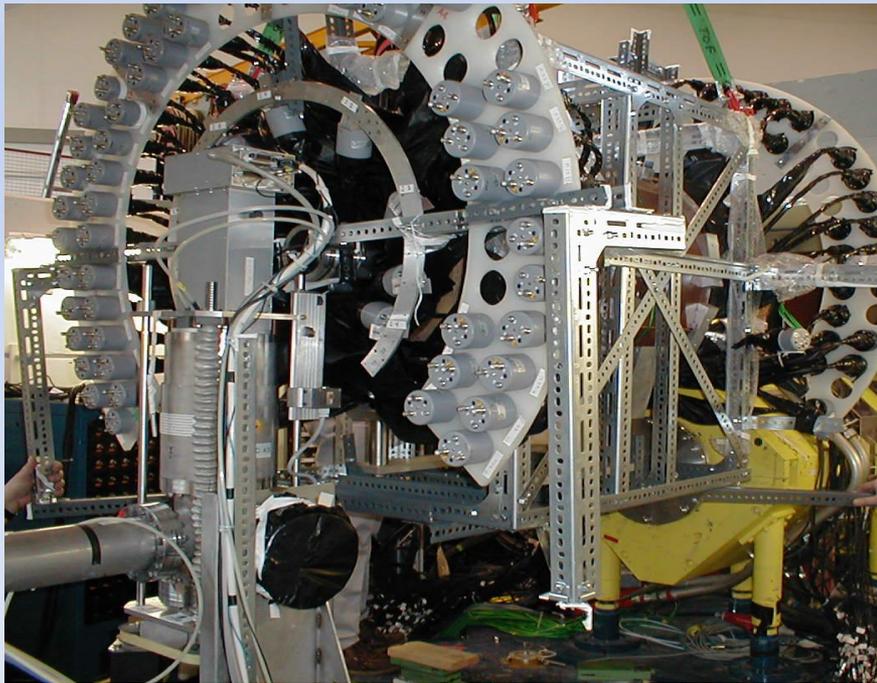
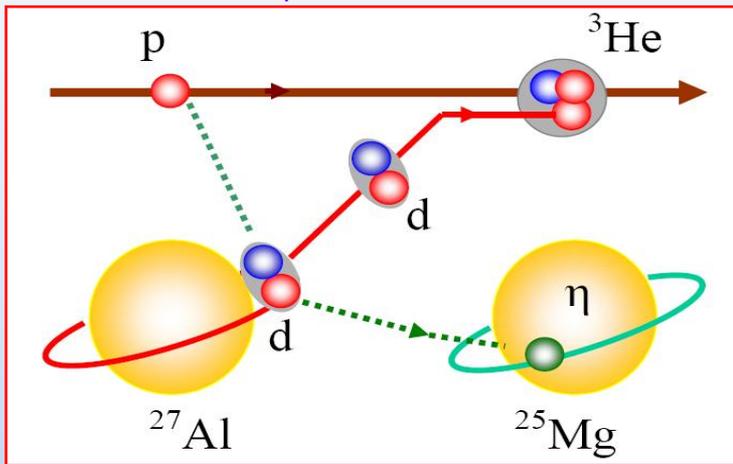
Current Indian activities in this field:

- COSY – BARC: Pionic atoms, Eta production, Eta mesic nuclei
- India collaboration at WASA(COSY), PANDA(FAIR) [IIT Mumbai, BARC, VECC]
- Contributions to theory (SINP)
- MIPP (FNAL)

ACTIVITIES OF THE BARC GROUP GEM (COSY), WASA and PANDA

- **Eta-Nucleus bound state study and the ENSTAR detector:**
- η -nucleus Final State Interaction Studies ($p^6\text{Li} \rightarrow ^7\text{Be}\eta$)
- **Investigation of Charge Symmetry Breaking effects and pi-eta mixing angle from a precision measurement of**
$$R = \sigma(\text{pd} \rightarrow ^3\text{H}\pi^+) / \sigma(\text{pd} \rightarrow ^3\text{He}\pi^0)$$
- **High precision eta- mass measurement**

Formation of Bound States

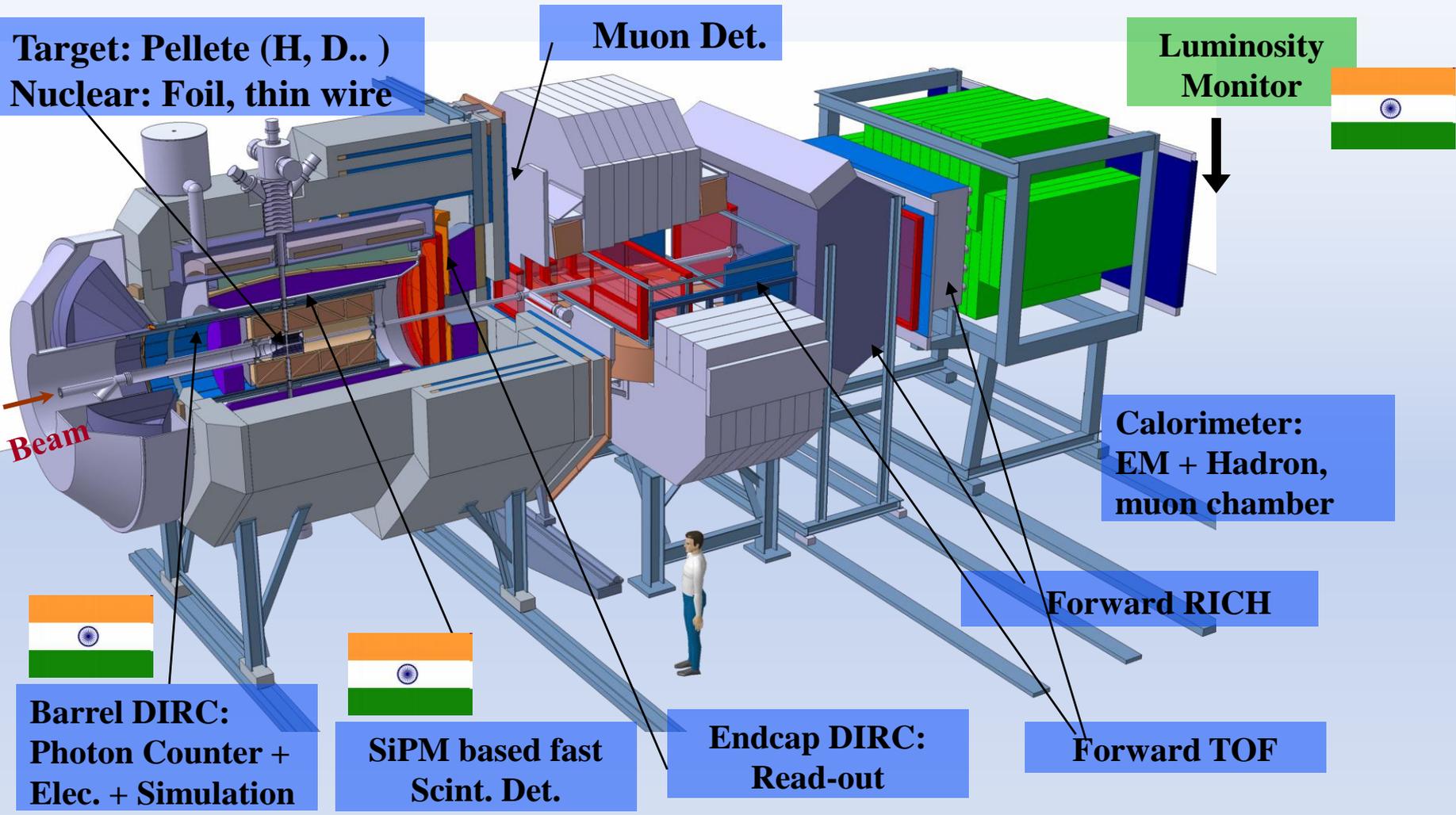


Strong indication of η -bound state in missing mass spectrum

Phys Rev C 70 2009 012201(R)

Phys Rev C 82 2010 041001(R)

PANDA Spectrometer: overview & possible Indian contribution



Target spectrometer: $\theta > 5$ deg.
Located inside a solenoid, $l=2.5$ m,
 $\varnothing=0.8$ m, $B \sim 2$ T

Forward spectrometer: $\theta < 5$ deg.
(vertical) & < 10 deg. (horizontal)

Contributions to Theory

1. Interaction between nucleons and mesons in coupled channels K-matrix approach
2. Covariant theory for hypernuclear production using pion, proton and photon probes
3. Study of $K^- + p \rightarrow K^+ + \Xi^-$ reaction using effective Lagrangian model

R. Shyam and O. Scholten, Phys. Rev. C **78** (2008) 065201.

R. Shyam , O. Scholten and H. Lenske, Phys. Rev. C **81** (2010) 015204.

R. Shyam, Progr. Part. Nucl. Phys. 61 (2008) 212

S. Bender, R. Shyam and H. Lenske, Nucl. Phys. A **839** (2010) 51

R. Shyam, O. Scholten and A.W. Thomas, Submitted (2011)

Main Injector Particle Production Experiment at Fermilab (MIPP)

- MIPP –I has taken data and is analyzing results.
 - Has 2 Indian graduate students, several Indian visitors (U.Panjab, U.Banares)
- MIPP- II (Upgraded version of MIPP)
 - Electronics upgrade of MIPP-I (will run 150 times faster)
 - Can take place within 1 year of approval (i.e. many years before Project-X beams are available)
- Essential for neutrino experiments such as LBNE, INO
- Can use its charged kaon beams and excellent particle ID capabilities for hypernucleus physics
- Excellent venue to train graduate students from India
 - They get experience in hardware, commissioning the experiment, software and physics analysis in a period of 3 years.
- Indian institutions can contribute in testing and manufacturing the fast electronics needed.

MIPP Upgrade collaboration list

83 collaborators world wide, 15 from India

V.Singh, Banaras Hindu University, Varanasi 221005, India

M.R.Anantharaman, V.C.Kuriakose, M.Sabir, R.B.Thayyullathil
Cochin University of Science and technology, Kochi 682022,
India

B.C. Choudhary, University of Delhi, Delhi 110007, India

B.Bambah, R.Mohanta, E. Harikumar, University of
Hyderabad, India

A.K.Giri, Indian Institute of Technology, Hyderabad, India

V.Bhatnagar, A.Kumar, S. Mahajan, S. Sahijpal, A. Singh
Panjab University, Chandigarh, 160014, India

Brief Description of Experiment

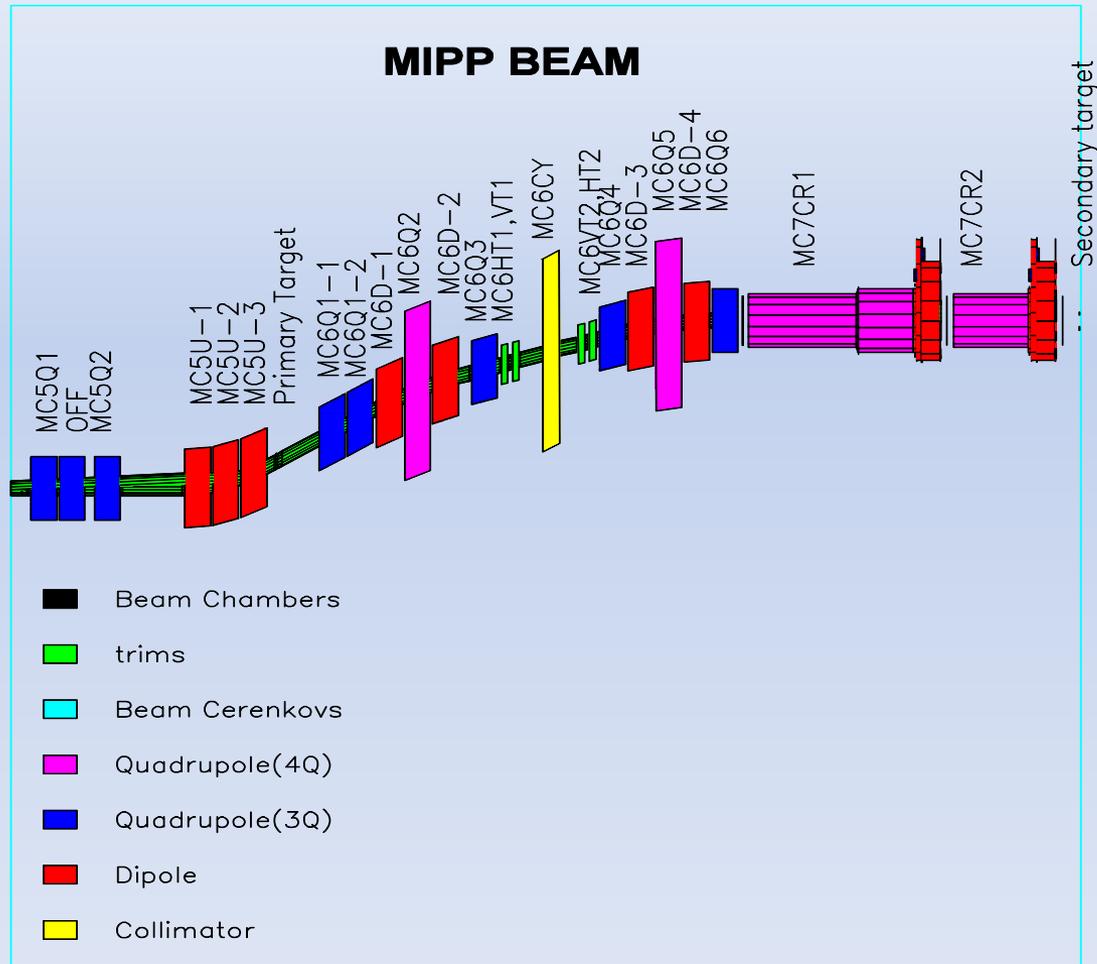
- Situated in Meson Center 7
- Uses 120GeV Main Injector Primary protons to produce secondary beams of π^\pm K^\pm p^\pm from 1 GeV/c to 85 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Using a TPC (Time Projection Chamber), MIPP measures momenta of \sim all charged particles produced in the interaction and identify the charged particles in the final state using a combination of dE/dx, ToF, MultiCell Cherenkov and RICH technologies.
- Open Geometry- Lower systematics. TPC gives high statistics 3D track reconstruction .
- Upgraded detector will run 150 times faster and will produce 5million events per day.
- Addition of the GSI Plastic Ball detector will enhance MIPP nuclear physics and hypernucleus capabilities.
- MIPP-I data is being analyzed. Major publications soon.

MIPP Upgrade measurements

- Nova/ Minerva medium energy target measurement.-15 million events in 3 days
- LBNE target design and particle production measurements
- Improve shower simulators (MARS, Geant4..). Plastic ball recoil detector will detect recoil neutrons from nuclei. Important for calorimeter compensation mechanisms.
- Measurement of production on nitrogen for cosmic ray + atmospheric neutrino experiments. Essential for INO.
- Hypernucleus physics using charged kaon beams and identified kaons and lambda particles in the final state.
- Missing Baryon Resonances measurements
- More detailed Studies of the strong interaction using excellent acceptance and particle identification
- Beams of tagged neutrons (where neutron energies are known event to event) have been demonstrated. Useful for nuclear physics

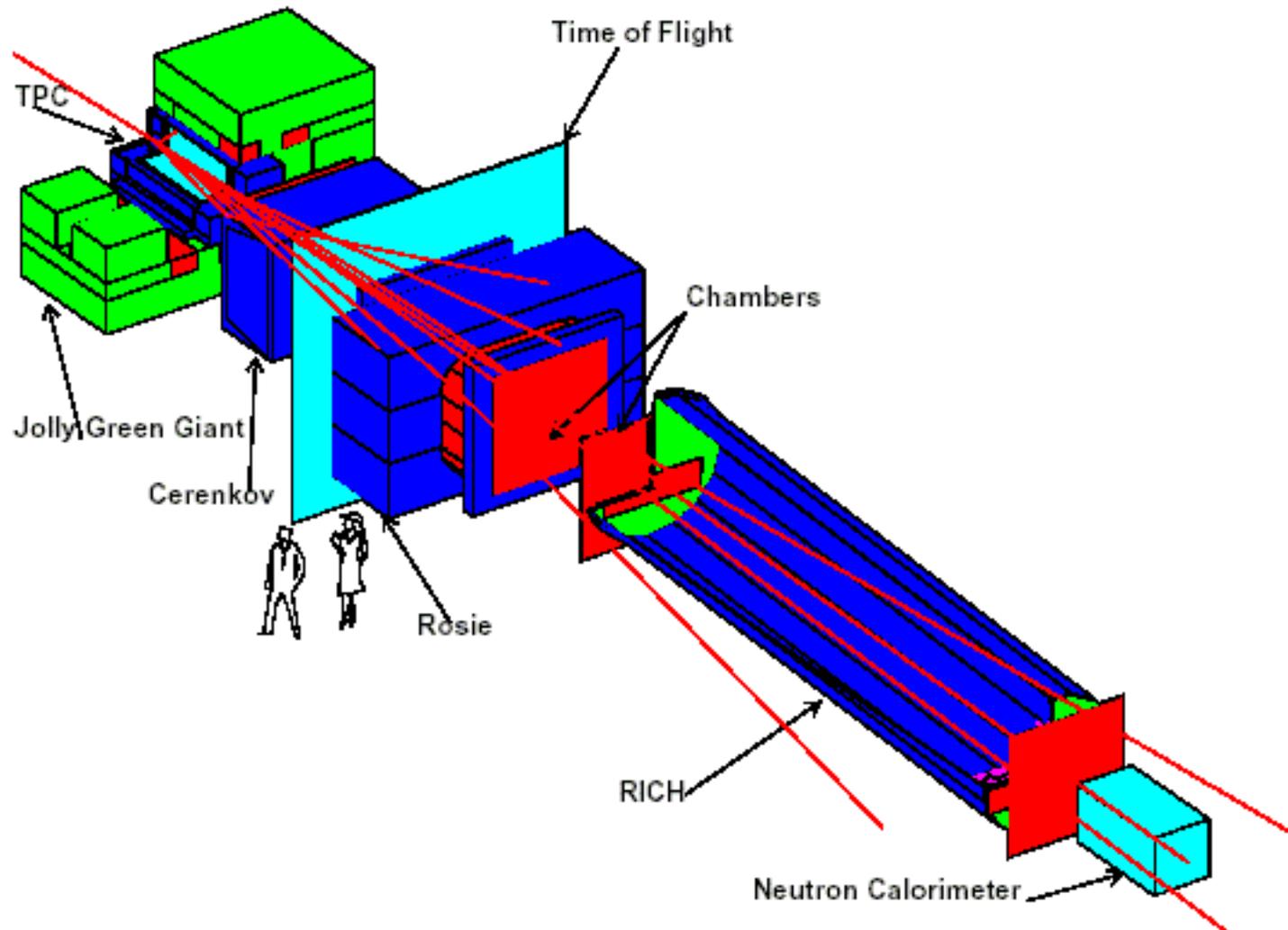
MIPP Secondary Beam

Installed in 2003. Excellent performance. Ran it successfully in MIPP from 5-85 GeV/c secondaries and 120 GeV/c primary protons. Excellent particle ID capabilities using 2 Beam Cerenkovs. 6 beam species (π^\pm, K^\pm, p^\pm) in the momentum range ~ 1 -120 GeV/c



MIPP

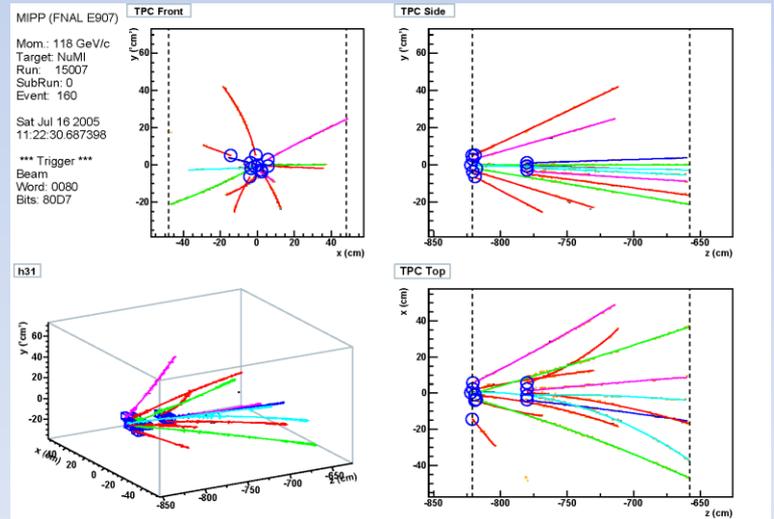
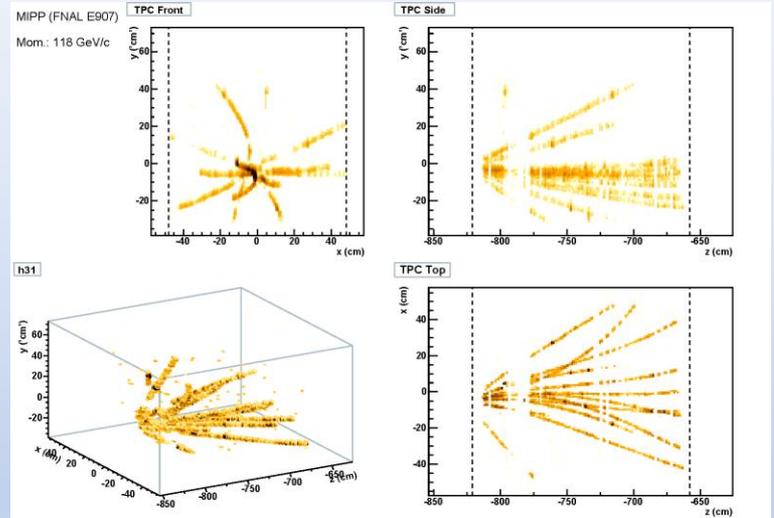
Main Injector Particle Production Experiment (FNAL-E907)



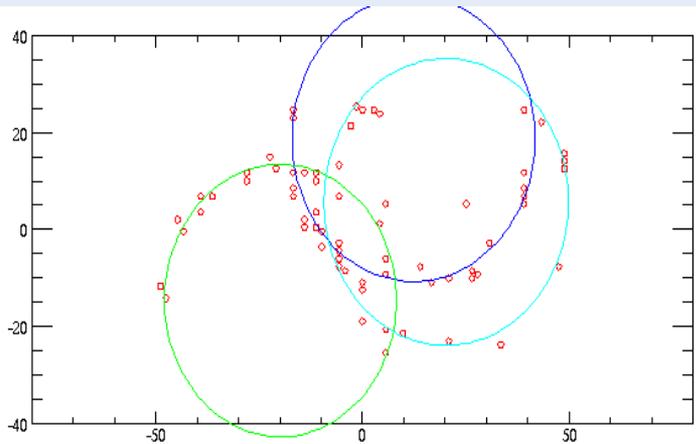
MIPP-I Installation in progress--~2003



MIPP TPCC



RICH rings pattern recognized

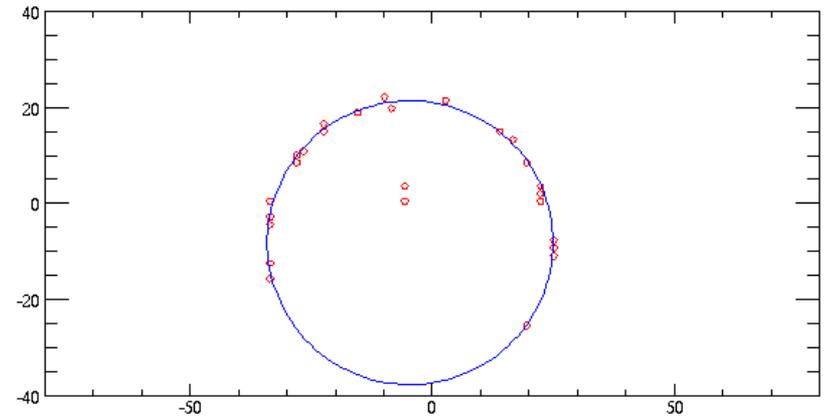


MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 92

Wed Aug 11 2004
13:53:56.864750

Version: 0
Trigger: 10000008

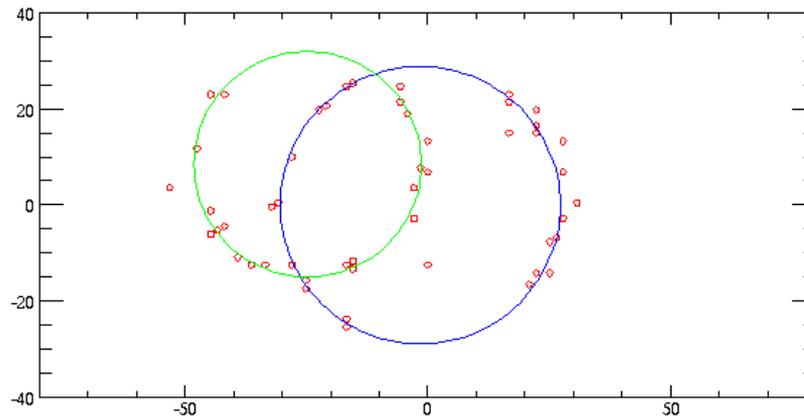


MIPP (FNAL E907)

Run: 9121
SubRun: 0
Event: 100

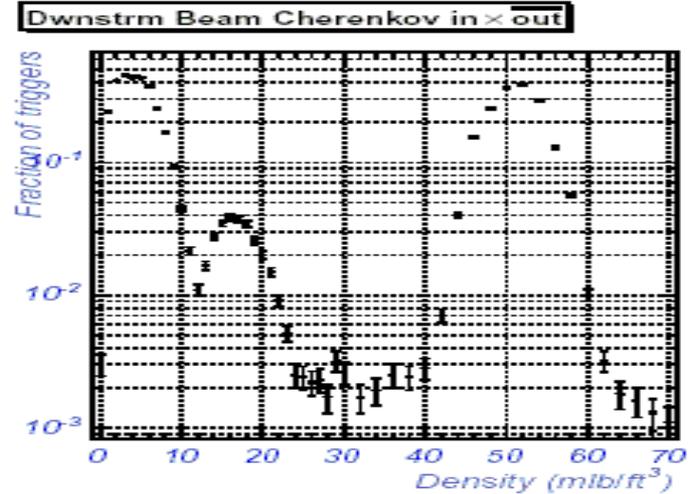
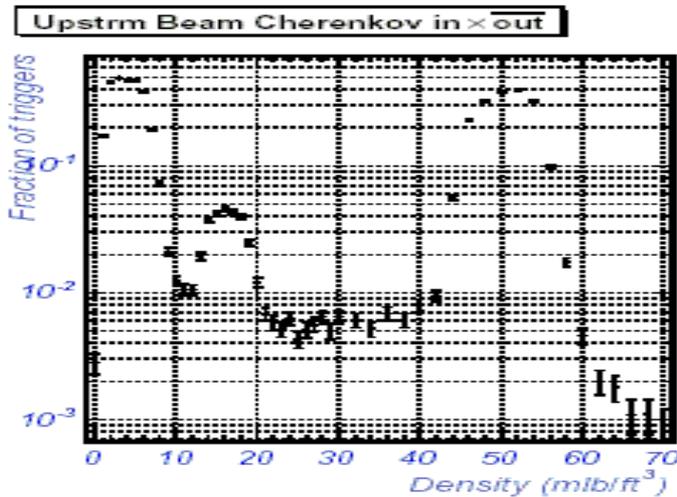
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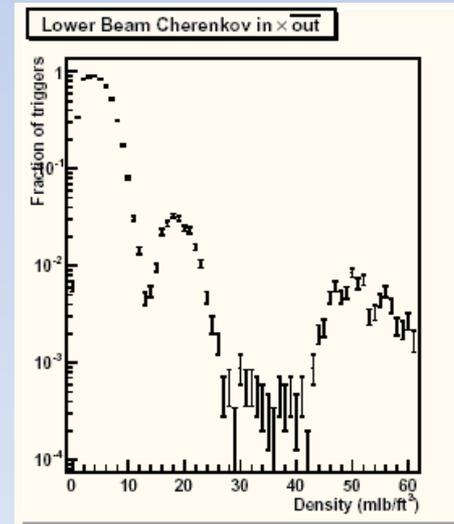
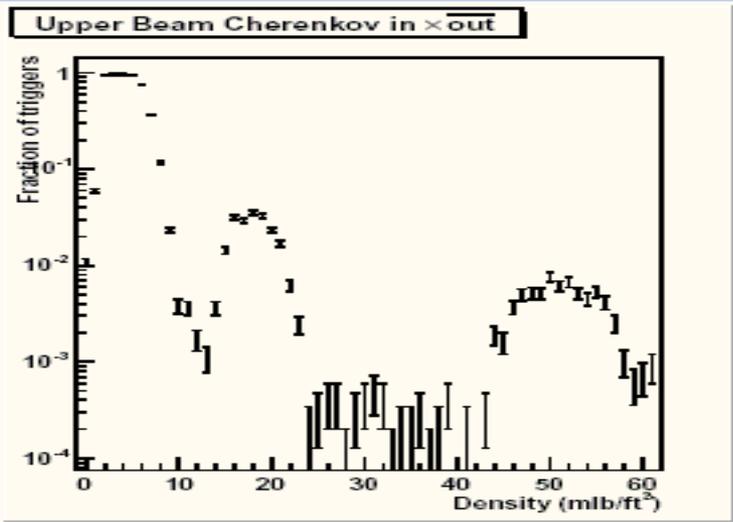


Beam Cherenkovs – Helps identify beam particle

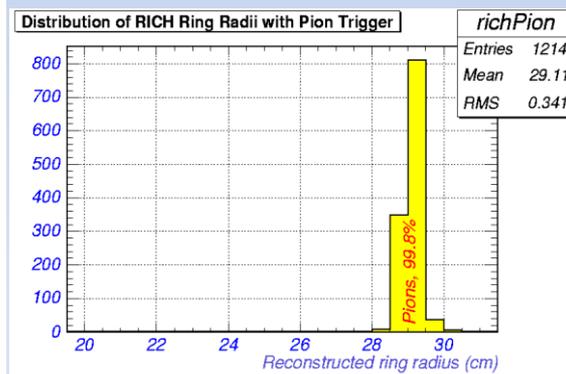
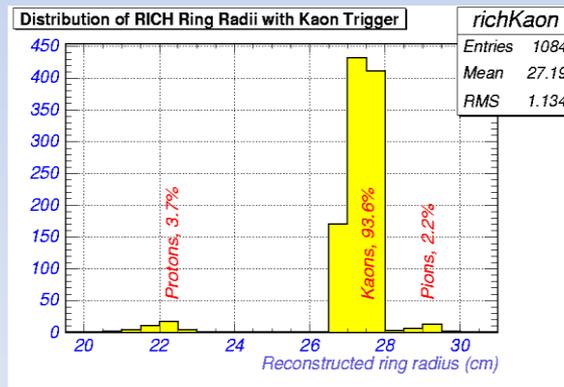
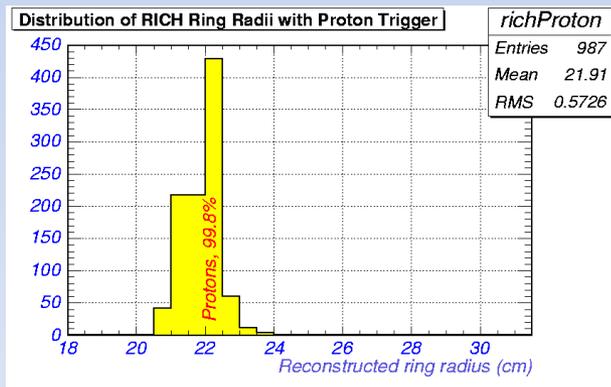
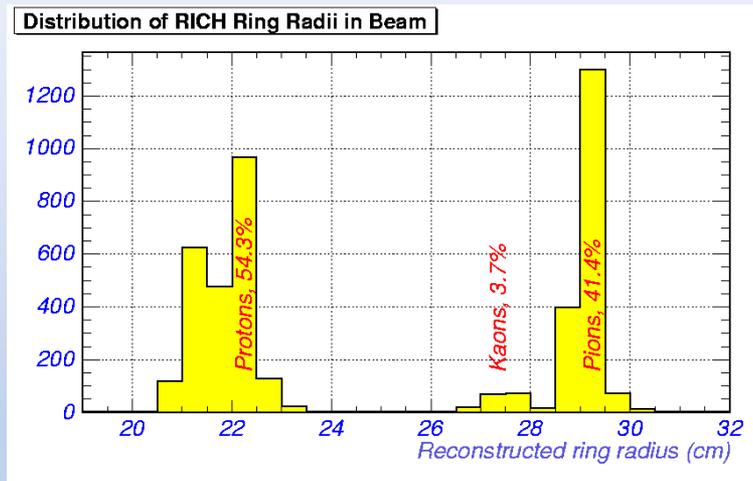
+40
GeV/c



-40
GeV/c



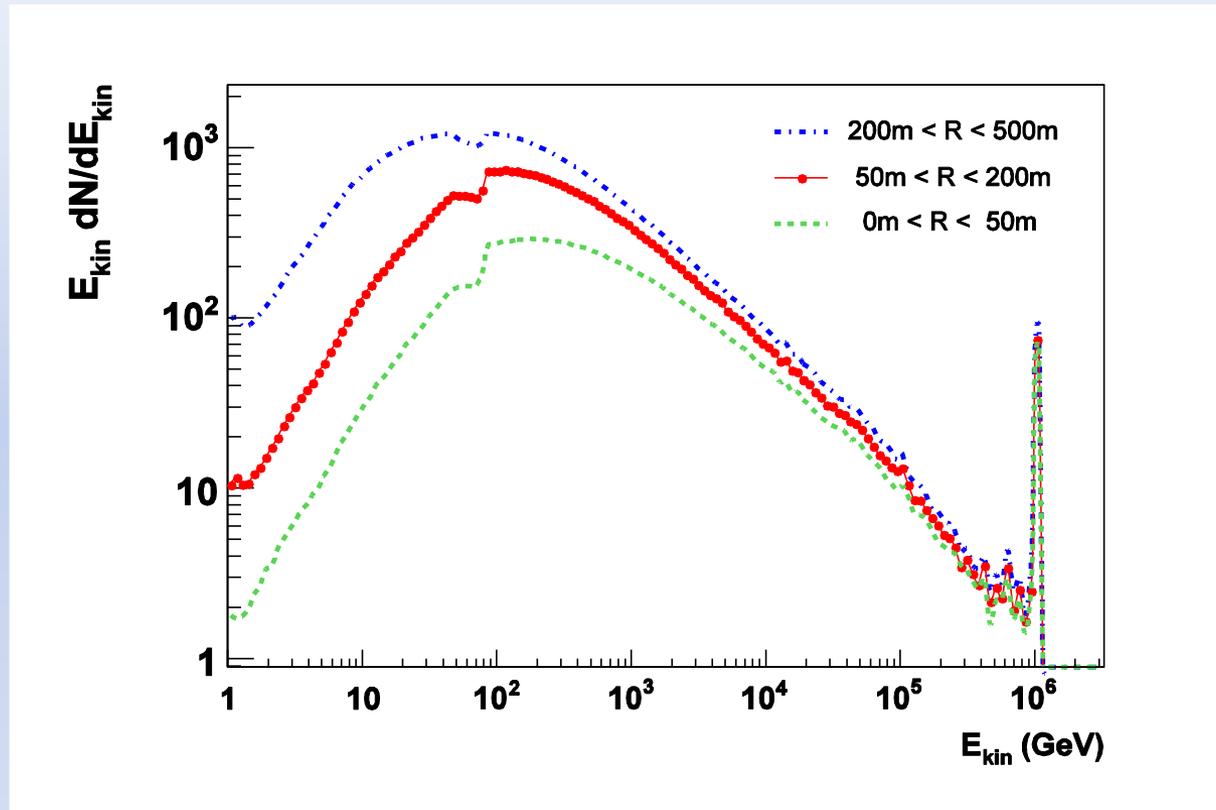
Comparing Beam Cherenkov to RICH for +40 GeV/c triggers – No additional cuts!



The MIPP Upgrade Proposal in a nutshell

- MIPP upgrade consists of replacing the electronics of every sub-detector using more modern designs. For the TPC electronics, ALTRO/PASA chips have been acquired and prototype boards have been designed.
- The Plastic Ball detector will be added as a new system to detect recoil pions, protons, neutrons and photons (below ~ 100 MeV in energy).
- All sub-detector electronics are in prototype stage. Each card has been designed.
- Total estimated cost of fabricating the electronics if done in the U.S is $\sim \$1$ Million. (Rs 4.5 Crore).
- Upgrade essentially consists of fabricating the electronics board in quantity and testing them.
- Upgrades to the beamline, rewinding the TPC and upgrades to the DAQ complete the list.

Meurer et al –Cosmic ray showers Discontinuity-Gheisha at low energies and QGSJET at higher energies-Simulation of air showers. This problem cannot be solved by measuring a nitrogen target at one or two energies.



Cosmic ray showering not understood. 2 models show a factor of 2 discrepancy. Nitrogen measurements by MIPP will fix this.

INO needs for particle production

- INO hopes to measure the sign of δm_{32}^2 by measuring the difference between neutrino and anti-neutrino induced events where the neutrinos are produced by cosmic ray showers in the atmosphere. In order to have maximal sensitivity for this measurement, it is essential to know the relative rates of positive and negative pions produced in atmospheric showers.
- MIPP upgrade can measure the production of pions in nitrogen using proton and pion beams in the relevant energy range. The maximum of the cosmic ray showers happens to be at approx. the MIPP energy ranges.

The Plastic ball recoil detector

Important for calorimetric simulations and nuclear physics

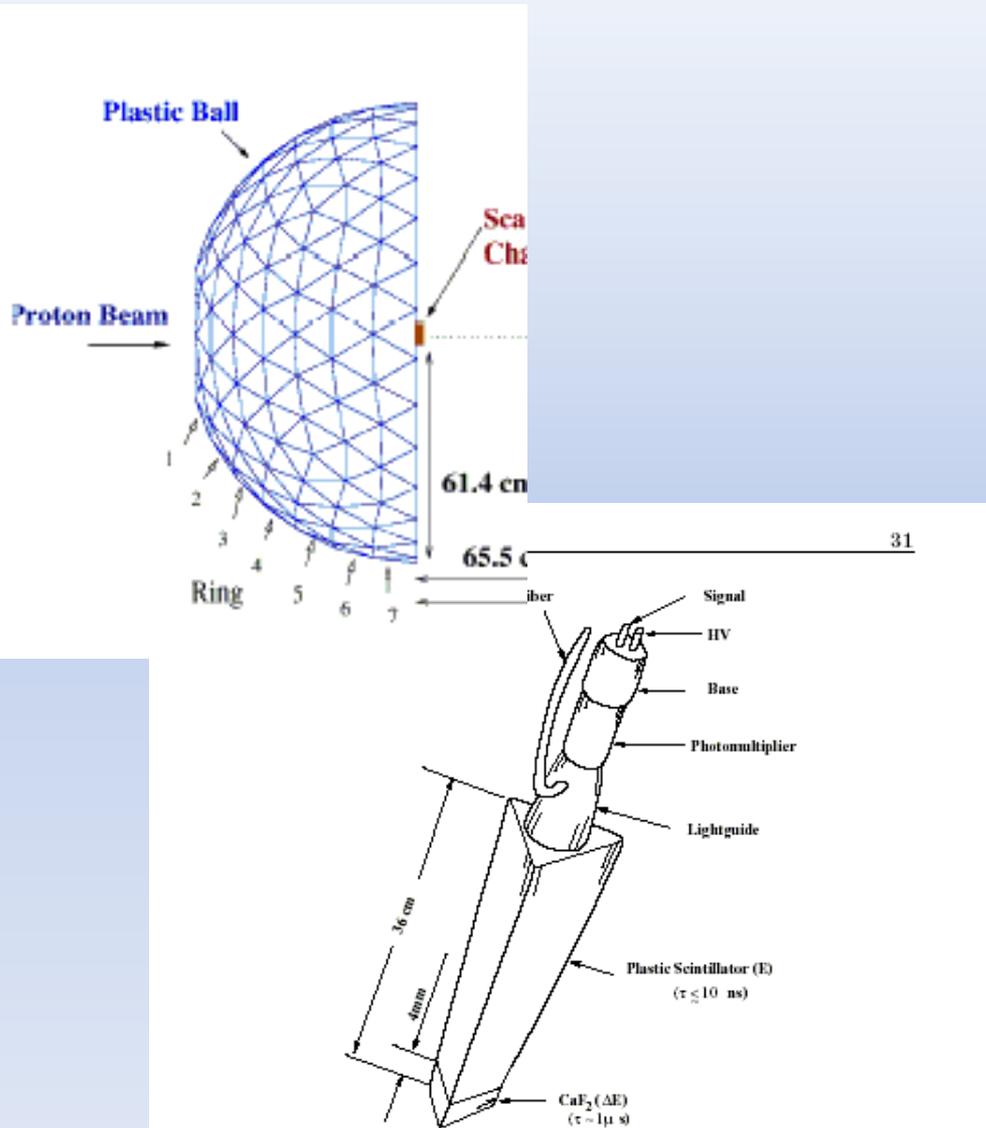
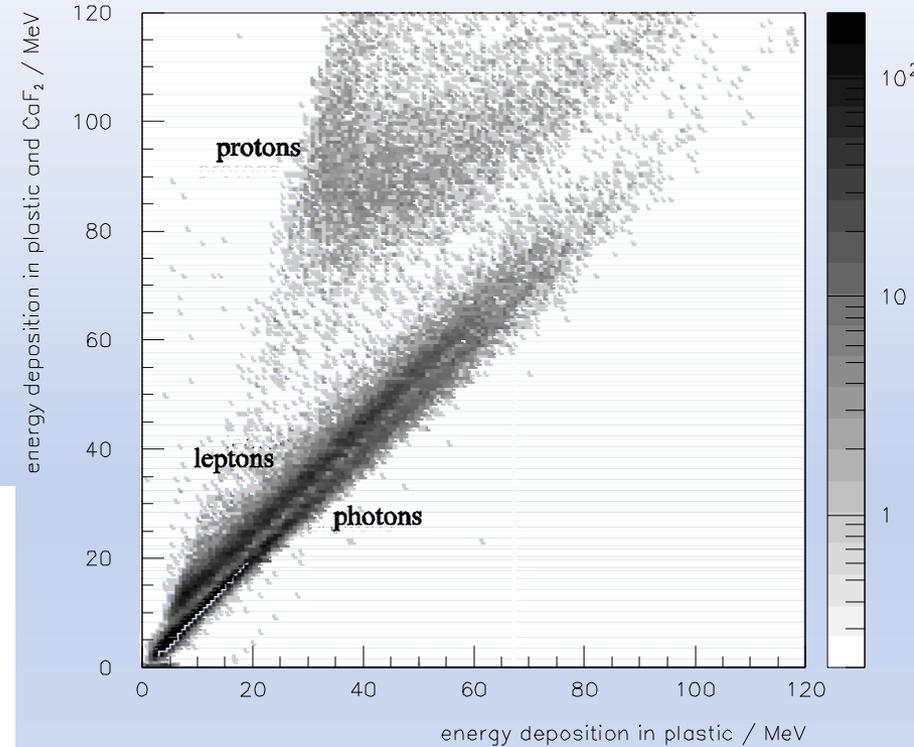


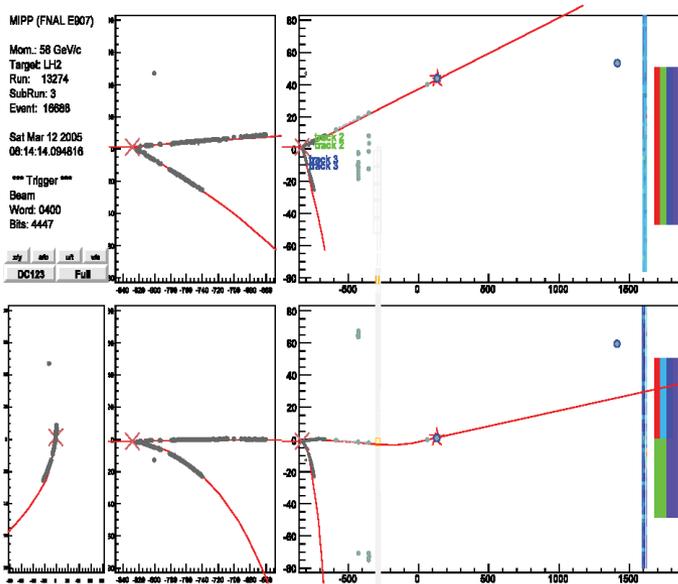
Figure 3.5: Schematic drawing of an individual Plastic-Ball detector.



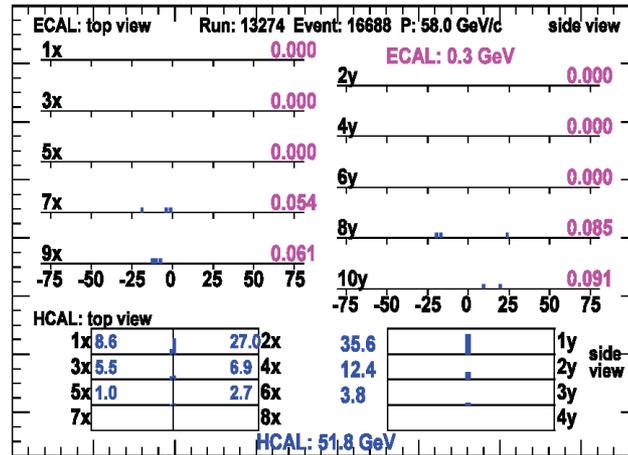
Detect recoil protons,
neutrons, photons and
charged pions, kaons

Tagged Neutron candidates observed in MIPP data

Tagged neutral candidate 2 --58 GeV pp interaction



Tracking Display



Calorimeter display

pp \rightarrow p n π^+

By measuring the final state proton and pion momentum, the neutron momentum can be tagged.

Neutrons as low as a few 100 MeV can be produced in the tagged mode.

Beam Momentum GeV/c	Proton Beam n/day	K+ beam K-Long/day	K- beam K-Long/day	Antiproton beam anti-n/day
10	20532	4400	4425	6650
20	52581	9000	9400	11450
30	66511	12375	14175	13500
60	47069	15750	14125	13550
90	37600			

Hypernucleus Physics with MIPP Upgrade

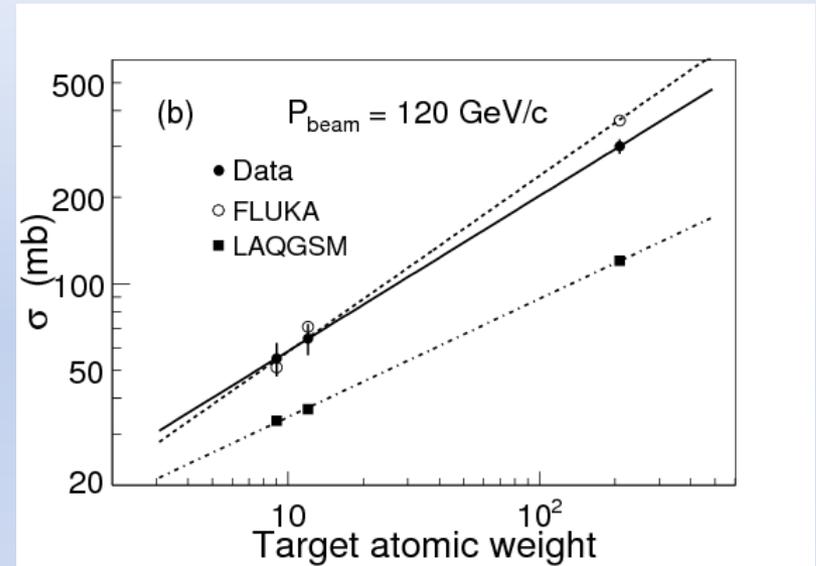
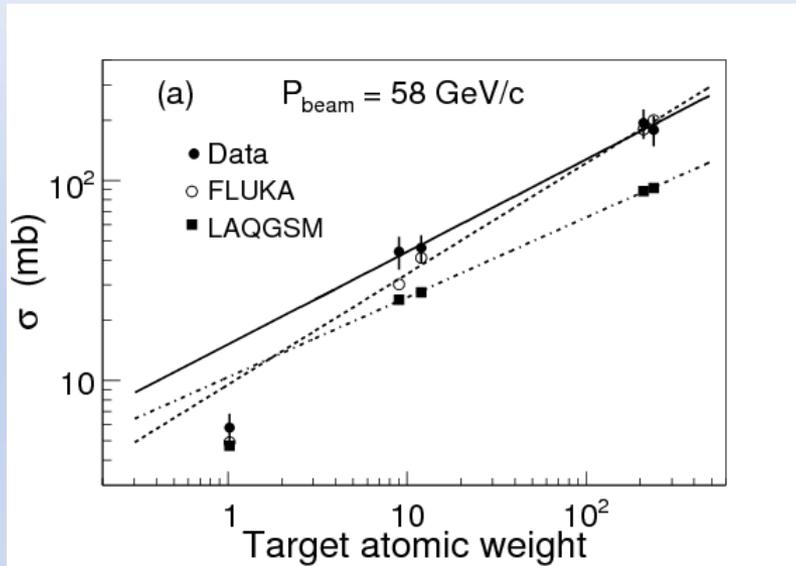
- MIPP upgrade will have kaon beams of both charges from 3 GeV/c up to 85 GeV/c.
- The plastic ball recoil detector can detect recoiling neutrons, pions, photons and protons from nuclear breakup.
- The TPC can measure the identity of the nuclear fragment by dE/dx for momenta below 1 GeV/c.
- Charged particles in the final state can be identified by TPC, time of flight, multi-cell Cerenkov and RICH technologies for the full momentum range.
- Strange neutral particles, K-Shorts, lambdas and anti-lambdas can be identified in the TPC.
- Using this arsenal of technologies, it should be possible to search for hyper nuclei of single and double strangeness.

Phd's so far and Indian Participation in MIPP-I

- Five PhD's awarded
 - Ratio of Pion Kaon Production in Proton Carbon Interactions (A. Lebedev, Harvard)
 - Measurement of Pi-K Ratios from the NuMI Target (S. Seun, Harvard)
 - Measurement of the Charged Kaon Mass with the MIPP RICH (N. Graf, Indiana) (published)
 - Charged pion production cross section using 120 GeV/c proton beam on carbon target (G. Aydin, Iowa)
 - Cross section measurements in the Main Injector Particle Production (FNAL-E907) experiment at 58 GeV/c (Y. Gunaydin, Iowa)
- 2 Indian students (Sonam Mahajan and Amandeep Singh from U. Panjab, Chandigarh) are at MIPP currently working on their theses.
- In addition, Dr. Ashok Kumar(Chandigarh), Dr.Venktesh Singh(Fermilab International Fellow, Banares), Arun Soma(Banares), Sourav Tarafdar(Banares) have spent time at MIPP as visitors.
- This can increase significantly with Indian participation in MIPP Upgrade.

Forward Neutron Cross Section Results

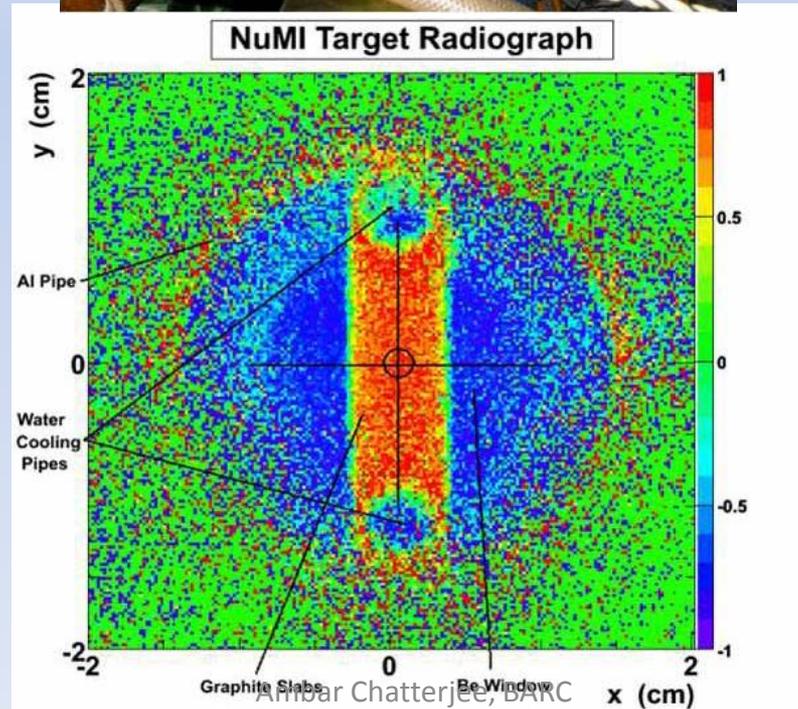
Phys. Rev. D 83, 012002 (2011)



Notice discrepancies between the 2 Monte Carlos and also the data and the Monte Carlos

NuMI Target analysis

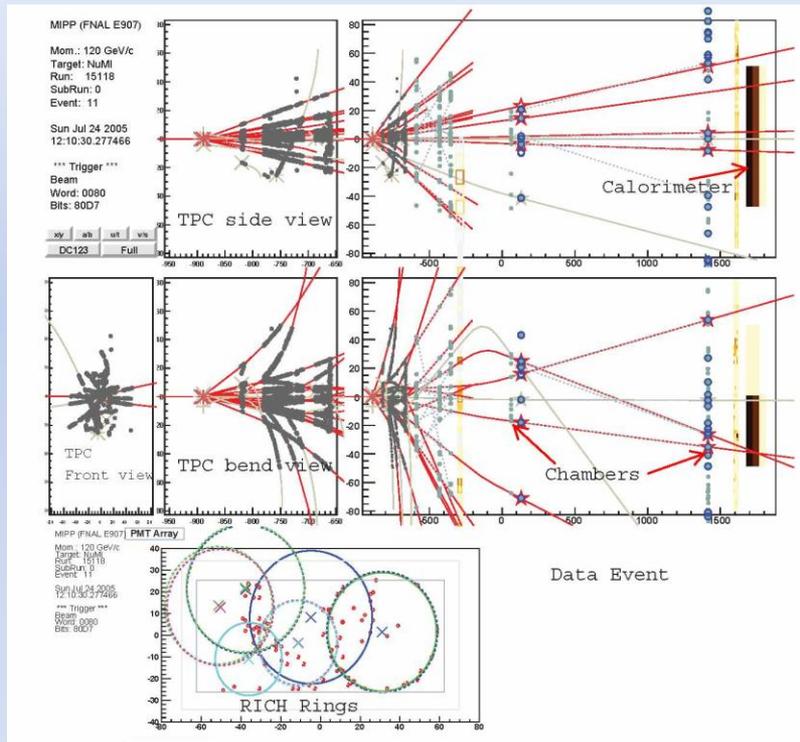
Actual NuMI target in MIPP upstream of the TPC. This target was then installed in NuMI.



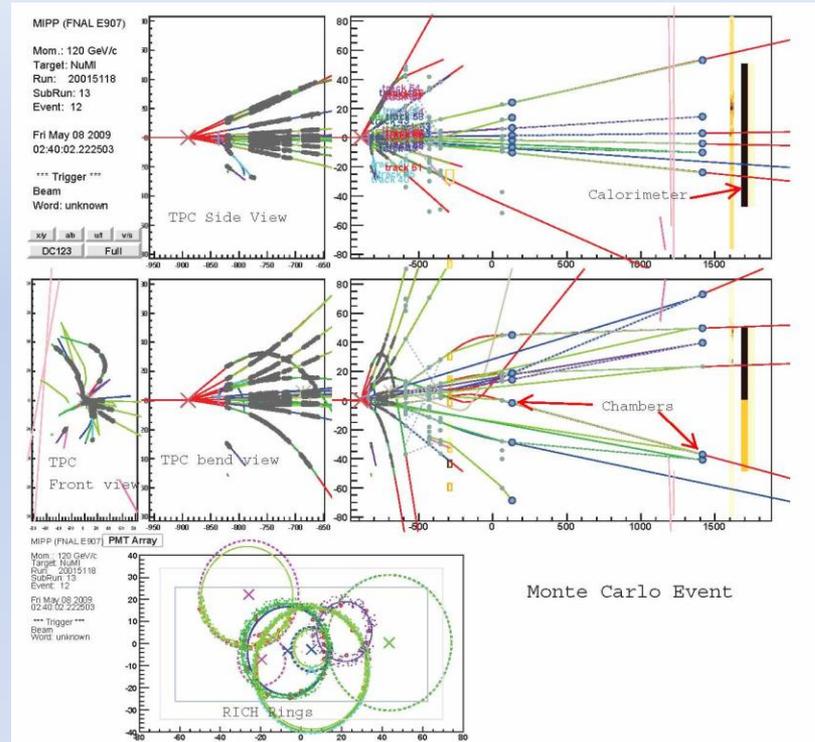
Radiograph of NuMI target in MIPP taken with a defocused 120 GeV/c proton beam

Event Displays

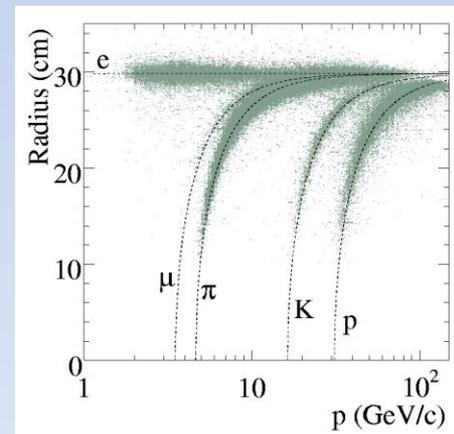
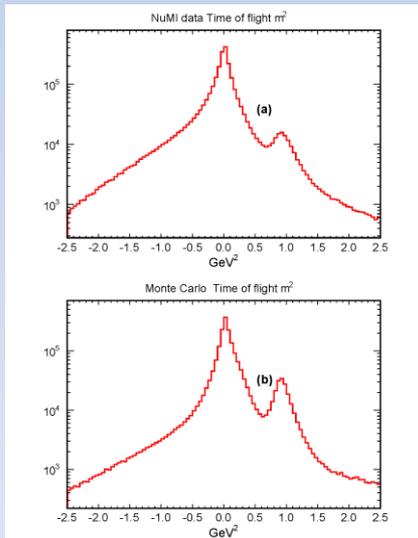
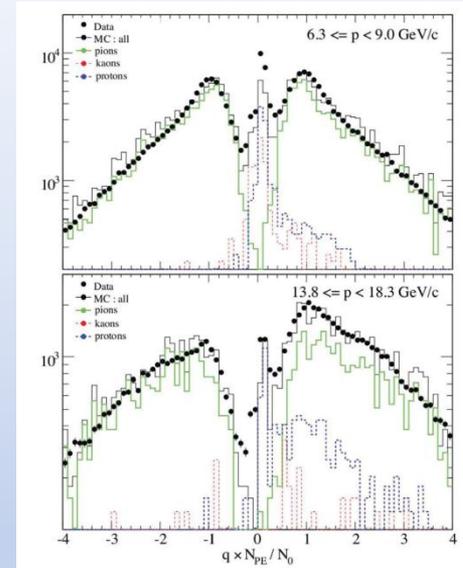
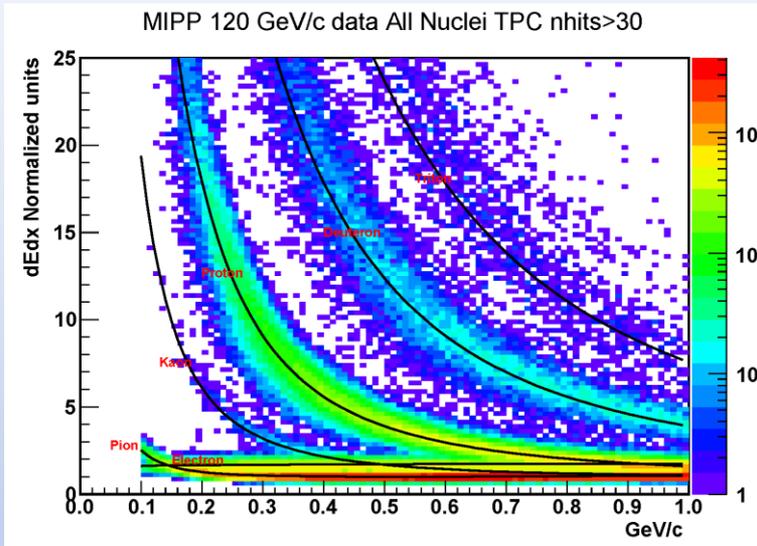
NuMI target data event



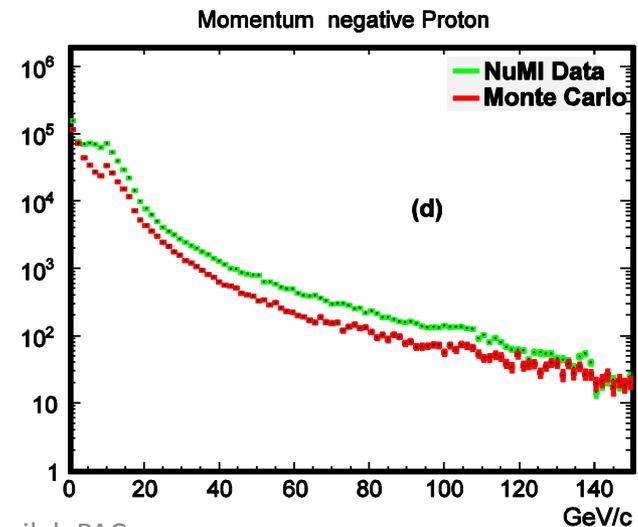
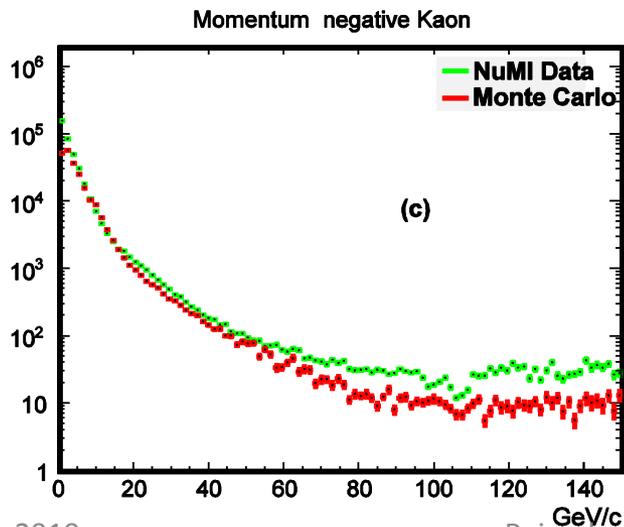
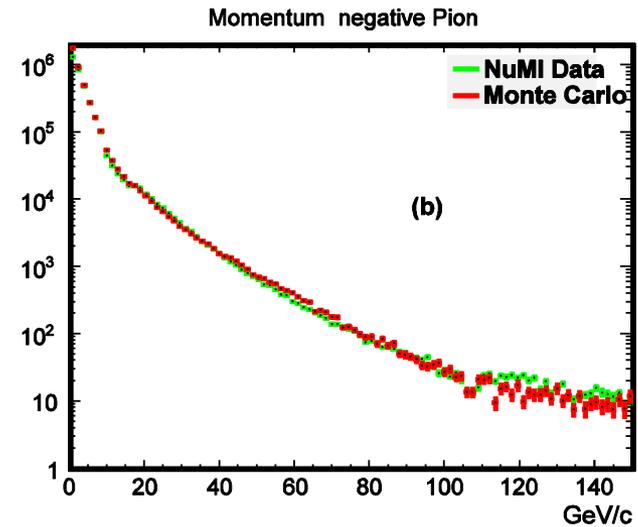
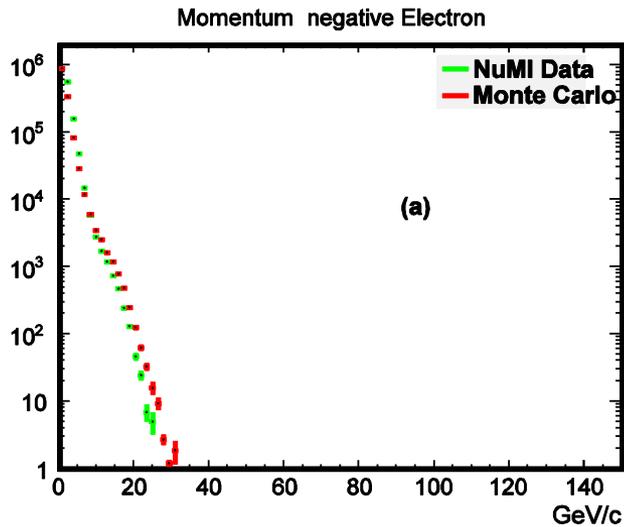
NuMI target Monte Carlo event with run dependent imperfections added



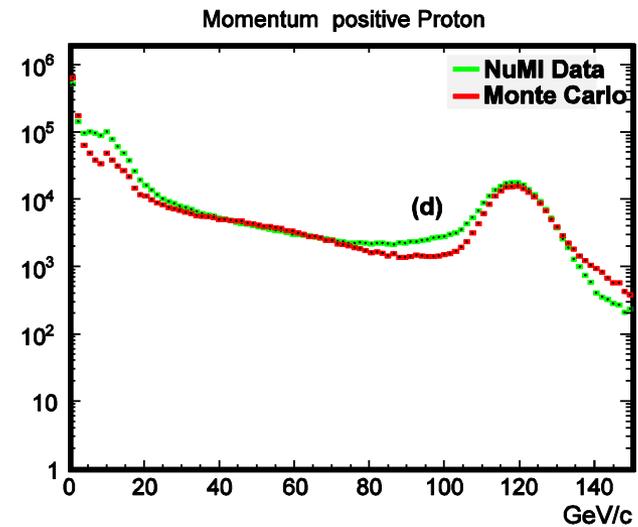
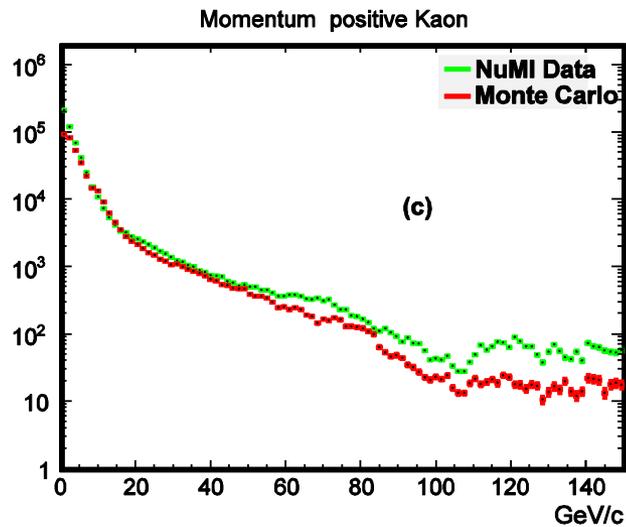
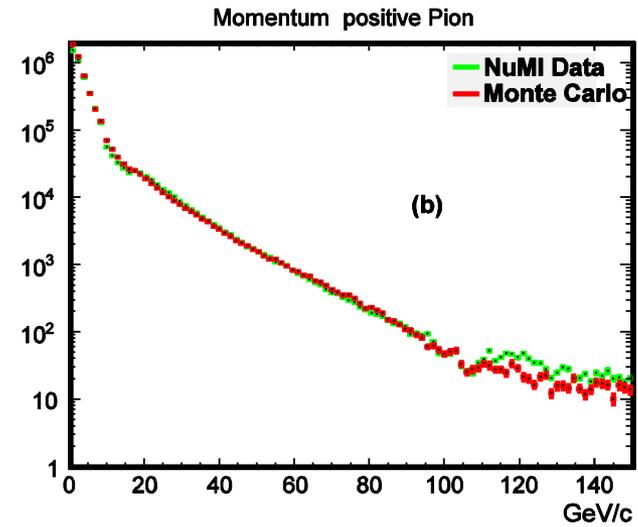
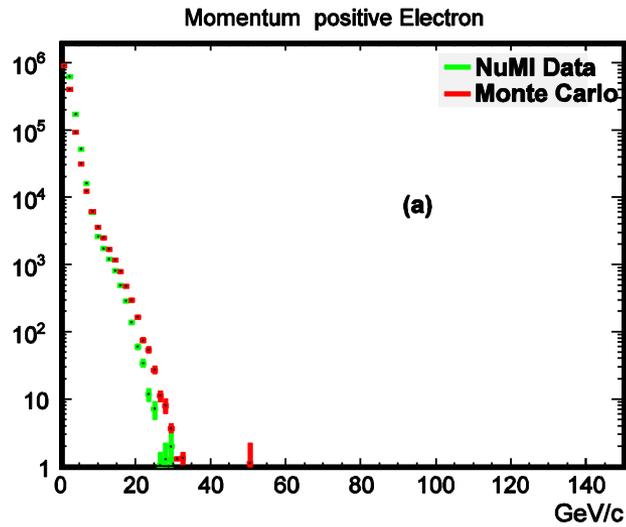
MIPP detector responses



Comparison of Data with MC for negatives

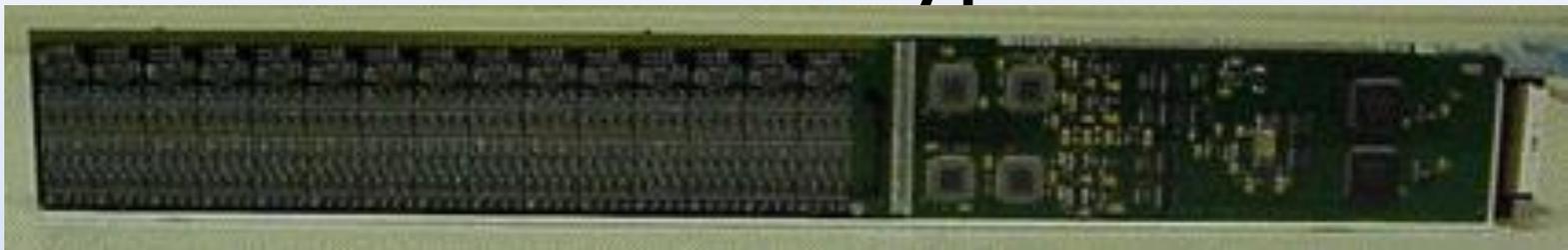


Comparison of Data with MC for positives



TPC boards-New Prototypes vs old

Old Stick



New Stick



Single
Altro/Pasa
unit

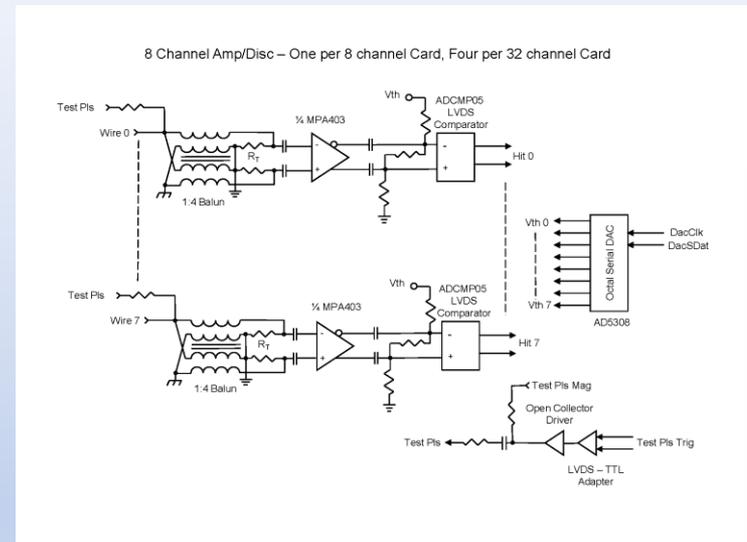


Buffer Board



Drift Chamber/ PWC readout Upgrade

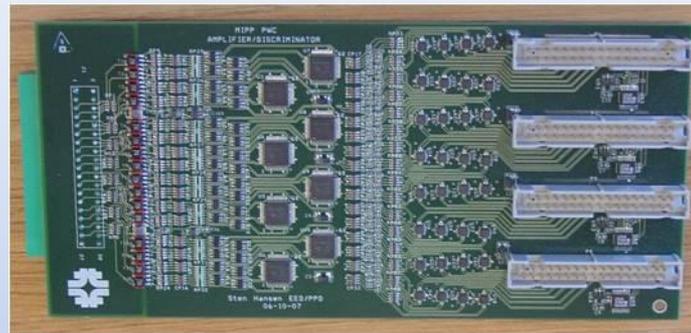
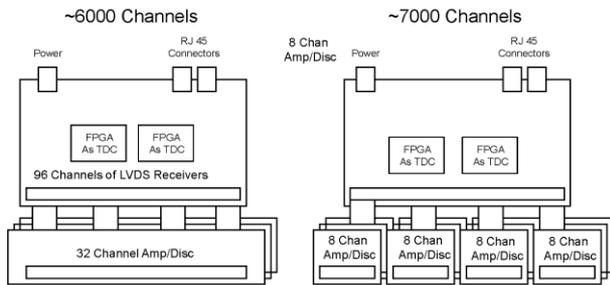
- Large PWC's use old CERN RMH electronics- Needs replacement.
- MIPP proposes a unified scheme for reading out both sets of chambers using a system that modifies the MIPP RICH readout cards by changing the latch to a TDC.
- Preamp cards being replaced Preamp/Discriminator front end cards.
- The RICH cards will store an entire spill's worth of events, which are readout in between spills.



8 Channel amplifier card

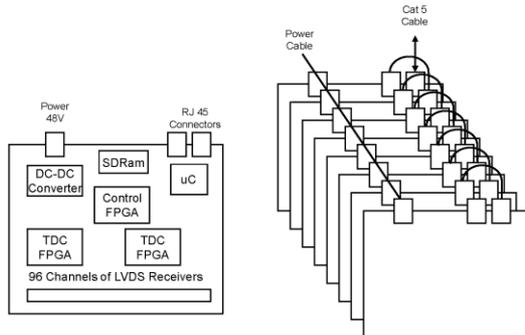
Chamber Card prototypes

High-Speed Differential Interfaces
 "Cyclone II devices can transmit and receive data through LVDS signals at a data rate of up to 640 Mbps and 805 Mbps, respectively. For the LVDS transmitter and receiver, the Cyclone II device's input and output pins support serialization and de-serialization through internal logic."



32 channel amplifier card

TDC Card Arrangement



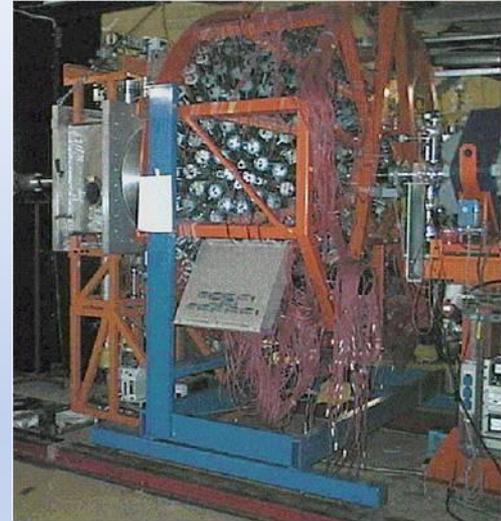
96 channel TDC card

TOF & CKOV readouts

- 106 TOF + 12 T0 +96 Ckov channels
- Plan to use the back end provided by MIPP readout controller.
- Front end likely to be TriP-T chip (also used by MINERvA(ADC)) and a high resolution TDC chip (TDC-GPX from ACAM 30ps resolution). Will buffer an entire spill. Delay cables will be eliminated.

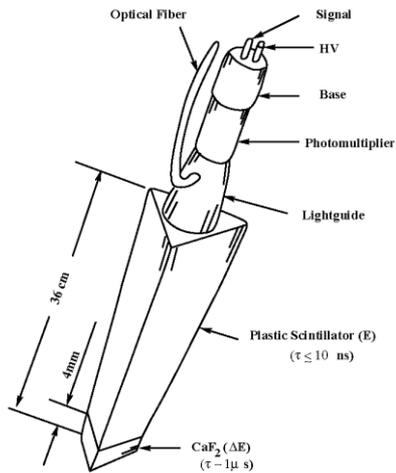
Plastic Ball Recoil Detector

- Plastic ball detector is available. GSI/KVI have joined MIPP. We will install a hemisphere in MIPP. Mounting details to be worked out. Need the ability to remove the detector to repair it and the TPC.
- Transportation to Fermilab.
- GSI/KVI will play a lead role in making this happen
- Detector will help in all aspects of MIPP data including tagged neutral beams, missing baryon resonances and hadronic shower simulation data.

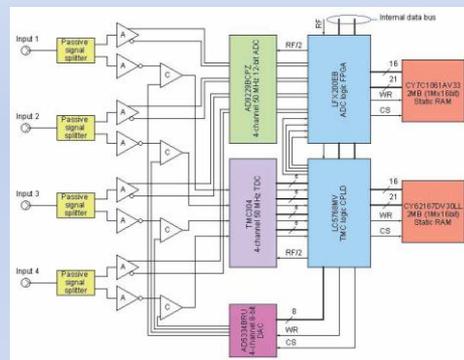


Picture of the full plastic ball at KVI

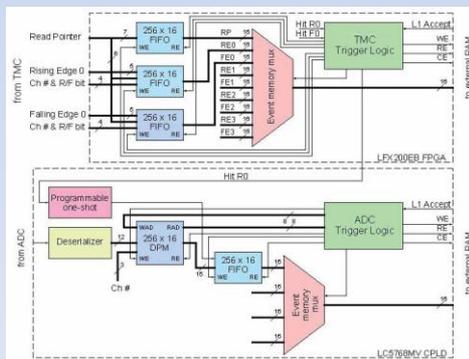
Plastic ball readout



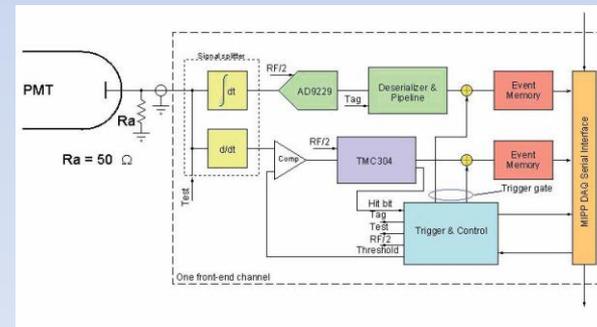
Plastic ball front end board



4 channels

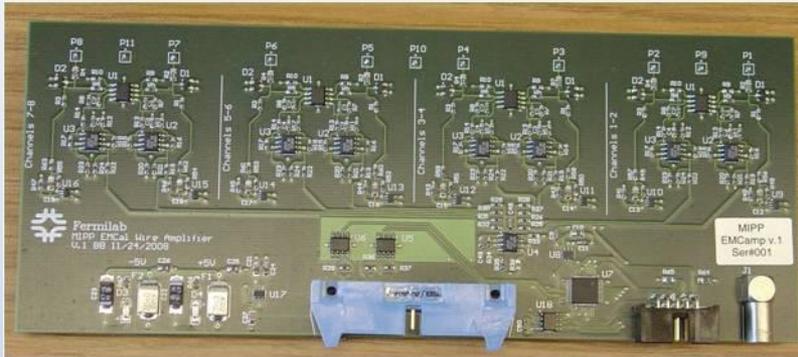


Plastic ball trigger logic

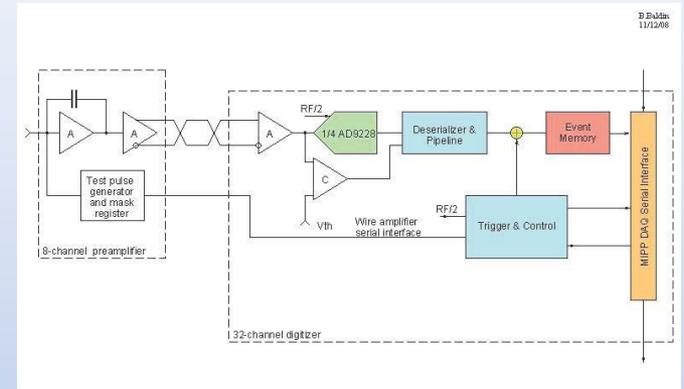


Plastic ball front end board schematic

EM Calorimeter wire amplifier board



EM cal front end 8 channel wire amplifier board



Block diagram of EM cal front end 8 channel wire amplifier board

EM cal front end board

HCAL has currently 8 PMT/ADC channels. We plan to adapt a plastic ball readout module for this.

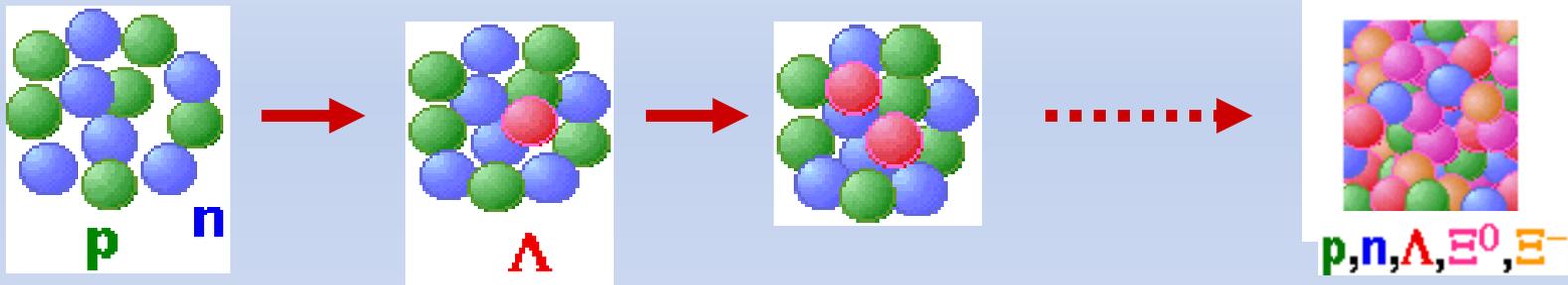
Conclusions

- MIPP Upgrade experiment will permit high quality, high statistics data on hadronic production to be acquired in a timely fashion.
- Data thus acquired needed by a variety of clientele.
- India stands to gain in the following areas.
 - Training new students in hardware, software and analysis techniques.
 - acquiring data needed for the INO
 - Participating in search for hyper nuclei
 - Acquire skills needed in fabricating state of the art electronics.

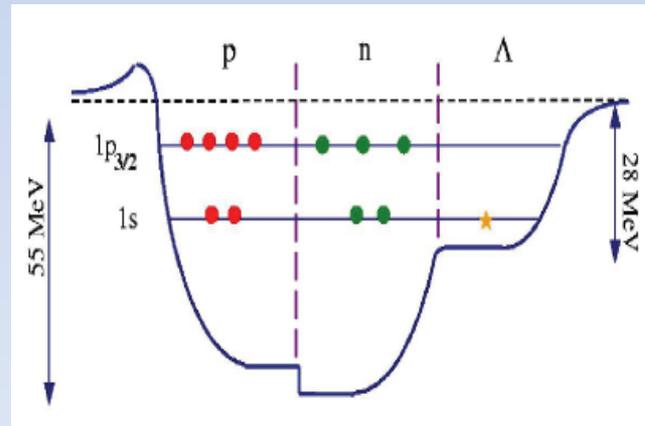
Thank You

What are Hypernuclei

- Hypernuclei are systems where at least one nucleon is replaced by a hyperon (Λ discovered 1953 – emulsion experiment).
- The hypernucleus is a laboratory to study hyperon-nucleon (YN) and hyperon-hyperon (YY) interactions
- Multi strangeness hypernuclei \Leftrightarrow Neutron stars (high core density)



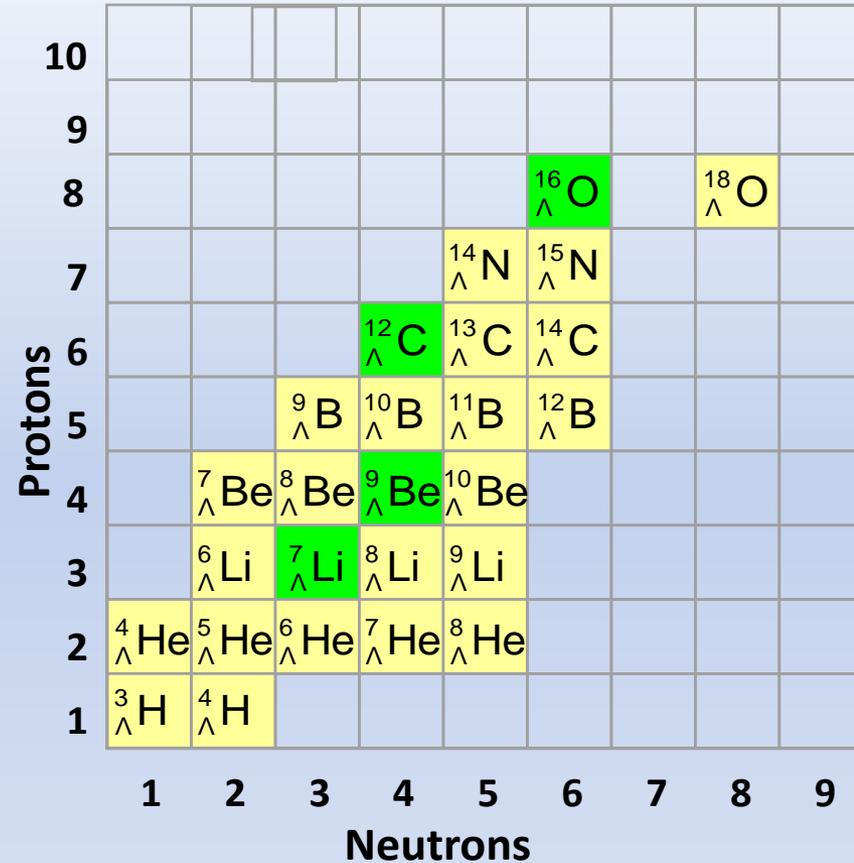
- Internal nuclear shells are not Pauli-blocked for hyperons.



A **hypernucleus** can be considered the outcome of a **genetic engineering manipulation** applied to the nuclear physics domain

The introduction of 1 (or 2) hyperons in a nucleus may give rise to various changes of the nuclear structure

- changes of the size and of the shape
- changes of the cluster structure
- manifestation of new symmetries
- change of collective motions

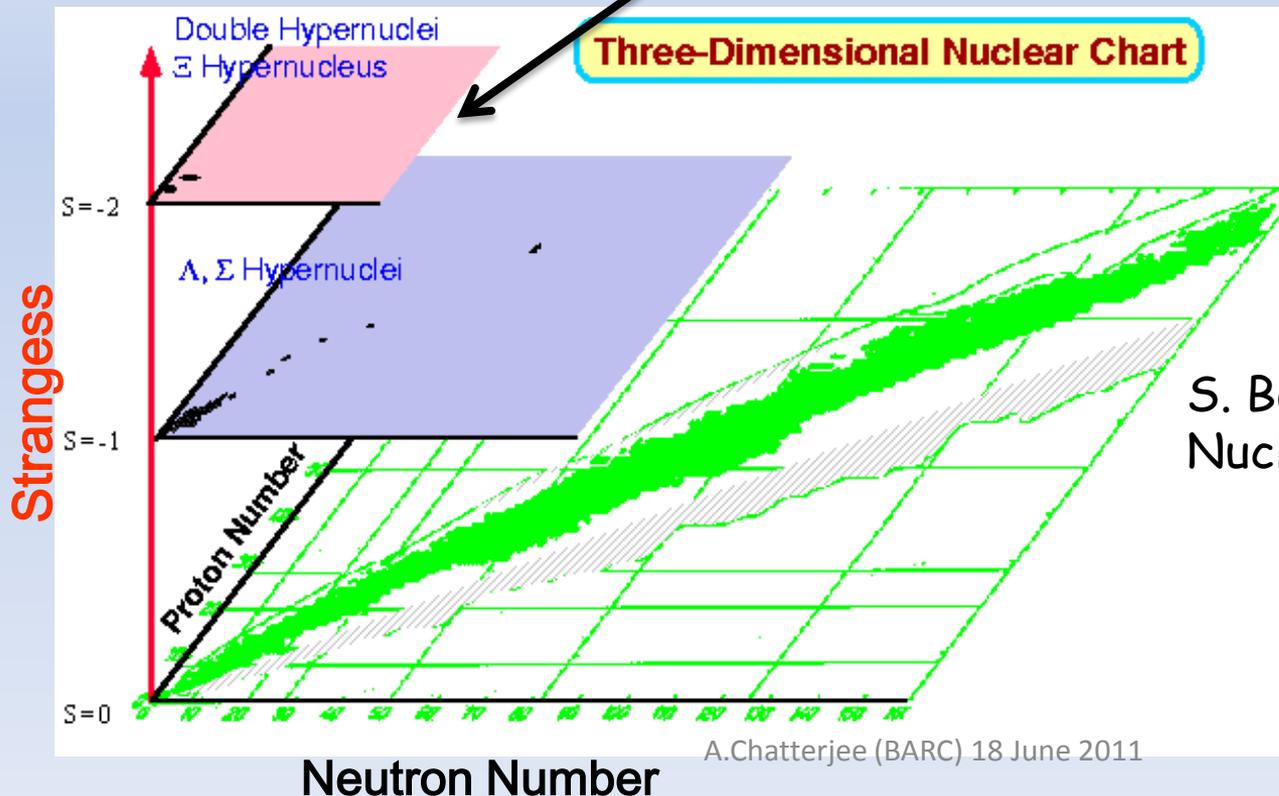


S = -2 systems study is not just a simple extension of what has been done for S = -1 system

$S = -2$ systems

A detailed and consistent understanding of the quark aspect of the baryon-baryon force will not be possible unless information on YY systems is available

Production of Hypernuclei at J-PARC by (K^-, K^+) reaction. Also possible in Project-X, MIPP experiment



S. Bender, **RShyam**, H. Lenske
Nucl. Phys., **A839** (2010) 51.

Existing information

S = -1 hypernuclei

Beginning evidence for S = -2 Ξ hypernuclei (BNL and J-PARC followup)

Needed

**Clear observation of Ξ and $\Lambda\Lambda$ hypernuclei
 Ω hypernuclei (S = -3)**

Neutron rich ${}_{\Lambda}A$

Decay widths especially non-mesic channels

$\Lambda N \rightarrow NN$

Missing baryon Resonances

- Partial wave analyses of πN scattering have yielded some of the most reliable information of masses, total widths and πN branching fractions. In order to determine couplings to other channels, it is necessary to study in elastics such as

$$\pi^- p \rightarrow \eta n; \pi^- p \rightarrow \pi^+ \pi^- n; \pi^- p \rightarrow K^0 \Lambda$$

$$\gamma p \rightarrow \pi^0 p; \gamma p \rightarrow K^+ \Lambda; \gamma p \rightarrow \pi^+ \pi^- p$$

- All of the known baryon resonances can be described by quark-diquark states. Quark models predict a much richer spectrum. Where are the missing resonances? F.Wilczek, A. Selem
- “..this could form the quantitative foundation for an effective theory of hadrons based on flux tubes” – F.Wilczek

Nuclei of interest- 1st pass list

- The A-List
- H₂, D₂, Li, Be, B, C, N₂, O₂, Mg, Al, Si, P, S, Ar, K, Ca, Fe, Ni, Cu, Zn, Nb, Ag, Sn, W, Pt, Au, Hg, Pb, Bi, U
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- On each nucleus, we can acquire 5 million events/day with one 4sec beam spill every 2 mins and a 42% downtime.
- We plan to run several different momenta (1-85 geV/c) and both charges. For neutrinos we will also have p=120GeV on thick and thin targets.
- The libraries of events thus produced will be fed into shower generator programs which currently have 30 year old single arm spectrometer data with high systematics